Inertial detachment of sesame seeds from non-squander genotypes

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Abstract: In this study we have experimentally determined the inertial force for releasing seeds from the capsules of six non-squander sesame genotypes that had been selected in IPGR- Sadovo, Bulgaria. The influence of seed moisture, size and direction of the inertial force over the percentage of released seeds has been analyzed. The results of the study have proved that releasing the seeds is possible by inertial impacts, which do not require breaking up of the capsules of the tested sesame genotypes. Compared to the threshing, this impact can be applied to harvesting the seed with twice higher moisture, without mechanical damages and with lower energy consumption.

Keywords: Sesame harvesting, mechanization, selection, energy saving technology, waste saving technology, damage saving technology.

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1 Introduction

Many non-squandering sesame genotypes have been selected recently and thus conditions for mechanized harvesting have been created (Queiroga et al., 2014; Vurarak et al., 2012). These genotypes hold the seeds to the placenta at maturation and open only tip of the capsules. These genotypes limit seed squandering before plant entering into harvester (Langham, 2000; Uzun et al., 2003; Georgiev et al., 2014). The genotypes that remain their capsules closed at maturation have been indicated as non-perspective (Langham, 2001).

Despite new-created genotypes, the grain harvester still causes great losses during sesame harvesting (Ishpekov at al., 2014; Yilmaz et al., 2008). When conditioned seed's moisture content is less than 8% - 10%, scattering losses dominate, caused by the harvester header. At higher moisture content, seed's damages dominate, caused by the threshing unit, which separates the seeds through breaking up the capsules.

In Bulgaria and other countries with similar climate, the humidity of seeds during their harvest is over 12% and therefore losses from mechanical damaging dominate (Trifonov et al., 2013). In these cases should be applied harvesting the seeds without breaking up the capsules. This approach is used for manual harvesting of the sesame seeds. The sharply-changing mechanical impacts are applied to the stem, which creates an inertial force that affects every seed. It causes exemption of the seeds without breaking up the capsules. Therefore, this way of seed release is named inertial. The harvested seeds are not mechanically damaged even if their moisture content is higher than the mentioned above.

The target of this study is to determine the indices of the inertial impact for detaching the seeds from non-squander sesame genotypes in order to assess opportunities for their harvesting without breaking the capsules.

2 Materials and method

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Target achievement requires:

- Designing of an experimental stand for imparting and determining the inertial force, acting on the seeds in the sesame capsule.
- Determining the percentage of detached seeds, depending on the imparted inertial force.

2.1 Experimental materials

Six sesame non-squandering genotypes were examined, all of which have been selected in IPGR - Sadovo, Bulgaria. Their names are Aida, Nevena, Valya, Milena, 4090 and 4079. During maturation, they open only the top of capsules and the placenta retains seeds up to full maturity.

20 plants of each genotype were cut, while they are still in technological maturity and their boxes are completely closed. In this condition, the capsules have been cut off and packed by fours in a paper-bag. Such bags have been prepared for all experiments. The bags have been left in the laboratory until opening the tops of capsules, which is a sign for starting the seed harvesting.

2.2Experimental stand

The parameters of the inertial impact for detaching the seeds from the capsules have been given and measured by a stand in laboratory conditions. It consists of pendulum apparatus and electronic system for measuring and recording the angle of rotation of the pendulum (Figure 1).

The apparatus consists of a base 1, on which is mounted the support 2 and the pendulum bar 3 with a plate 4. The scale 14 with trigger 15 is positioned to the support 2. It serves for fixing the pendulum at assigned angle and for its releasing after starting the measurement.

The electronic system consists of an incremental encoder - 11, data acquisition module USB-1208HS-2AO - 10 (www.mccdaq.com) and a computer - 8.

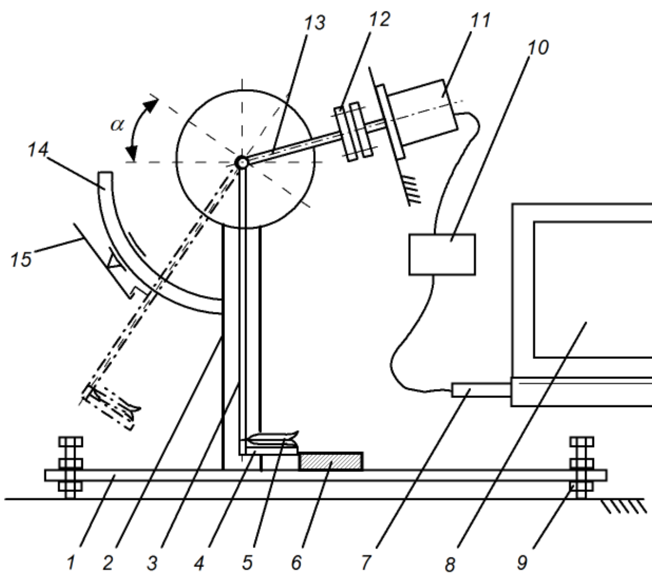

Figure 1 Experimental stand for investigation of inertial detachment of sesame seeds from the capsules.

1 - fundament, 2 - support, 3 - pendulum bar, 4 - plate, 5 - tested sesame capsules, 6 - anvil, 7 - USB port, 8 - computer, 9 –leveling screws, 10 - data acquisition module USB-1208HS-2AO, 11 - incremental encoder, 12 - clutch, 13 - pendulum shaft, 14 - scale, 15 - trigger.

Before each measurement four sesame capsules 5 are pasted on the plate 4 at the equilibrium position of the pendulum. The electronic system is started and the pendulum with testing capsules is deviated and locked at the assigned angle by the scale 14. After a second the pendulum is released by the trigger 15 and hits into the anvil 6, with which the tested capsules have no contact. The pendulum shaft 13 rotates the encoder's rotor 11 through the clutch - 12. The signal is read by module USB-1208HS-2AO - 10 and is delivered to computer - 8 via USB port - 7. The signal is displayed through a virtual instrument, which had been developed in the environment of LabView (www.ni.com/labview), (Figure 2).

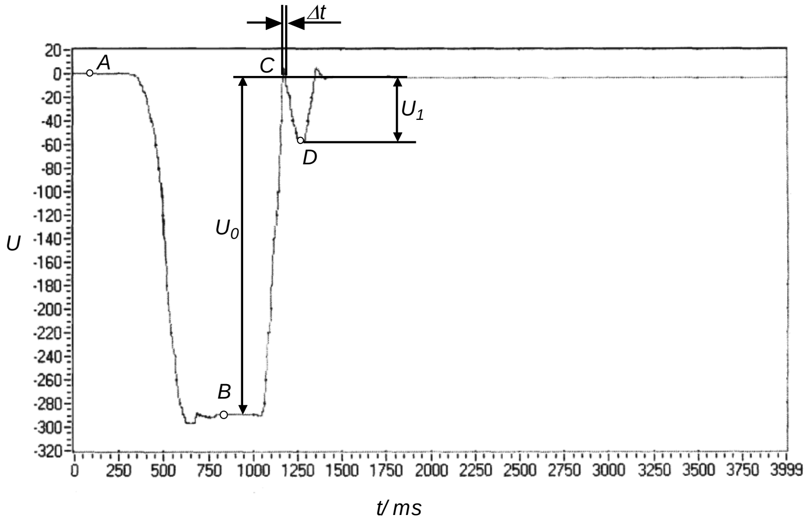

Figure 2 Graph of the signal from the measuring system

Point A - the pendulum is contacted with the anvil in the equilibrium position; *B* - the pendulum is diverted on 29°; *C* - impact of the pendulum into the anvil; *D* - the maximum deviation of the pendulum after the collision; U_0 - indication of the measurement system before the release of the pendulum; U_1 - indication of the measurement system at the pendulum rebound; Δt - the duration of the impact.

2.3 Determination of the inertial force acting on a single seed from the capsule

Due to the applied impact, each seed in the capsule has giventhe following inertial force

$$F_{in} = m_c a_{in}, \quad (1)$$

where:

m_c is the mass of a single sesame seed, *kg*,

a_{in} is the acceleration, which was given to the seed, m/s^2;

In this case, it is calculate das follows

$$a_{in} = \frac{(v_0 - 0)}{\Delta t}, \quad (2)$$

where:

v_0 is the capsule velocity just before the impact, *m/s*.

Δt is the duration of the impact, *ms*.

The impact duration is read from the signal of the measuring system (Figure 3). The velocity is calculated as follows

$$v_0 = l_b.\omega_0, \quad (3)$$

where:

l_b is the length of the pendulum bar 3, *m*.

ω_0 is the angular velocity of the pendulum before impact, s^{-1}.

It is determined as a function of the work done by the pendulum at falling from angle α (Ishpekov, 1997)

$$\omega_0 = \xi.\sqrt{\frac{l_b.g.(1-\cos\alpha).(m_b + 2.m_p)}{\frac{R_{cl}^2 m_{cl} + R_{enk}^2 m_{enk}}{2} + l_b^2.\left(m_p + \frac{m_b}{3}\right)}} \quad (4)$$

where:

ξ is the coefficient for accounting the friction losses in the bearings of the pendulum and of the incremental encoder;

g is the gravity acceleration, m/s^2;

m_b is the mass of the pendulum bar, *kg*;

m_p is the mass of the plate with the tested capsules, *kg*;

R_{cl} is the radius of the clutch, *m*;

m_{cl} is the mass of the clutch, *kg*;

R_{enk} is the radius of the encoder's rotor, *m*;

m_{enk} is the mass of the encoder's rotor, *kg*;

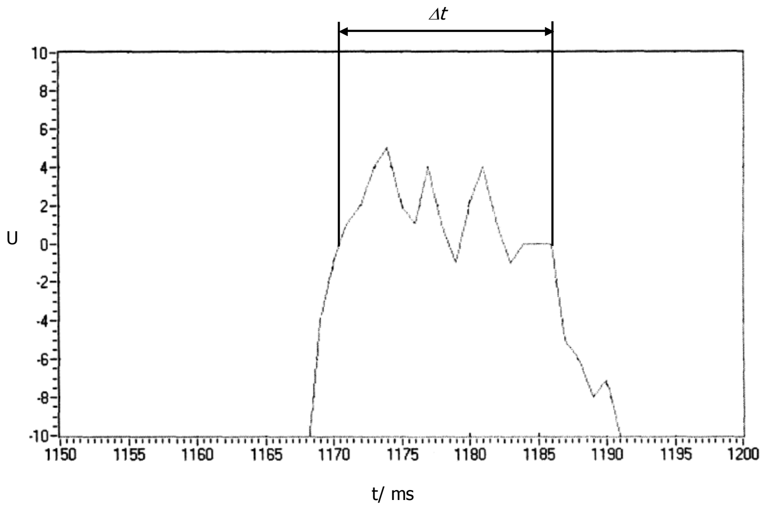

Figure 3 Duration of inertial impact after scaling the signal from the measuring system

2.4 Determining the percentage of inertial detached seeds

The seeds have been released from the capsules due to the inertial force. They have been scattered all over, causing the impossibility to collect them. Therefore, their amount has been determined in an indirect way by weighting of:

m_0 is the mass of tested capsules before the experiment, g;

m_{c1} is the total mass of the seeds, that fall as a result of slow rotating of the capsules with the top down and those that have been exempted from the capsules at their drying and maturation, g;

$m_2= m_0- m_{c1}+ m_{gl}$ - the total mass of the tested capsules and mass of the glue for their adhesive bonding to the pendulum, g;

m_{gl} is the mass of the glue for pasting the capsules on the pendulum, g;

m_3 is the mass of capsules after the inertial impact, g;

m_{c2} is the mass of the seeds remaining in the capsules after the impact, g.

The glue mass has been determined by the difference of the readings of the precision scales before and after deposition on tested capsules. This is acceptable because the mass of the used glue Loctide-406 does not change significantly during hardening. The mass m_{c2} was determined after manually breaking up of the capsules and removing the remaining seeds.

The mass of the seeds, leaving the capsules due to inertial effect has been calculated according to:

$$m_{c3}= m_2- m_3, g \quad (5)$$

The total mass of seeds has been determined as follows

$$m_c= m_{c1}+ m_{c2}+ m_{c3} , g \quad (6)$$

After that the percentage of m_{c1}, m_{c2} and m_{c3} from m_c has been calculated for the tested genotypes.

The percentage of m_{c1} determines the susceptibility to seed's squandering at shaking the plants by the wind or by low-speed mechanical impacts of the harvesting machines. It is possible to collect these seeds by a harvest, if the plants are fed into the machine smoothly and without significant inclination. The percentages of m_{c2} and m_{c3} depend on the applied inertial force as well as on the genotype.

2.5 Design of the experiments

A few one-way experiments have been conducted for investigating the percentages of m_{c1}, m_{c2} , m_{c3} from m_c. The experimental factors were:

- The moisture content of the seeds w, %;

- The inertial force acting on each seed F_{in}, N;

- The direction of inertial force towards length of the capsules;

- The number of inertial impacts.

The inertial force F_{in} has been changed through the fall angle of the pendulum in five steps, each 15°. The inertial force direction has changed in two variants. In the first the force has been applied in direction parallel to the length of capsule. In the second variant - the force has been perpendicular to the length of the capsules. The number of inertial impacts has been changed on three levels. The moisture content of the seeds has been changed in three levels by the period after the truncation of sesame plants from the roots.

The moisture content of the seeds and of the capsules has been measured with an electronic moisture meter of SigmaTech company, which has been calibrated by the manufacturer for sesame. The masses m_{c1}, m_{c2} and m_{c3} has been measured with an electronic scale.

Each measurement has been carried out with four capsules in three replications, which means that each experimental figure has been obtained by test of 12 sesame capsules.

The experimental results are used to calculate the descriptive statistical parameters and to evaluate significant differences between genotypes by t-test at a significance level of 0.95.

3 Results and discussion

The plant's parameters of the tested genotypes are presented in Table 1. At high moisture, the plants have been in technological maturity. Their capsules have been closed and the seeds have not been scattered. At middle moisture, all capsules have been opened and the majority of the seeds have been attached to the placenta. At low moisture part of the seeds have been detached from the placenta, but remained in the capsules.

Table 1 Parameters of tested genotypes

Genotype	Yield of seed from a single plant (g)	Number of capsules from a single plant	Average seed mass in a single capsule (g)	Moisture content (%)					
				high		middle		low	
				seed	capsule	seed	capsule	seed	capsule
Aida	7.9 ±2.11	112 ±6.2	0.070	20.5	35.8	15.1	22.5	10.2	18.5
Nevena	10.6 ±3.32	160 ±6.7	0.066	19.8	33.2	14.7	20.1	11.5	17.5
Valya	13.4 ±3.82	172 ±6.1	0.077	19.2	33.7	14.7	20.7	11.2	17.7
Milena	12.6 ±3.04	175 ±5.0	0.072	19.3	32.5	14.6	21.2	9.9	18.6
4090	8.5 ±2.02	158 ±5.4	0.053	20.3	34.1	14.9	18.3	10.2	18.5
4079	8.2 ±2.18	162 ±6.3	0.050	20.0	33.3	14.6	22.8	10.7	16.4

During maturation the seed's moisture decreases and influences on significantly changing of the percentages m_{c1}, m_{c2} and m_{c3}, (Figure 4). The moisture reduction increases m_{c1} and decreases m_{c2} linearly. The percentage of seeds, leaving the capsules varies in more complex way because of the inertial effect - m_{c3}. When the conditioned moisture is 20.5%, then m_{c3}= 0. At moisture of 15.1%, m_{c3} is near 40%. If moisture is still reduced then m_{c3} is decreasing due to increase of m_{c1}. The way of changing of percentages m_{c1}, m_{c2} and m_{c3} depending on seed's moisture is identical for all genotypes except Valia. For this genotype the graphs of m_{c1}, m_{c2} and m_{c3} are straight lines, which are parallel to the abscissa (Figure 5, Figure 6). Its value of m_{c1}=71.0 % and the values of m_{c2} and m_{c3} are very small.

Obviously, when a single impact applied parallel to the length of the capsules with an inertial force F_{in}=5.5E-4 N and an acceleration a_{in}=133.8 m/s^2, then the genotype Aida releases $m_{c1}+m_{c3}$= 52.4% of total seeds at moisture 15.1% and $m_{c1}+m_{c3}$= 85.1% at moisture 10.2%.

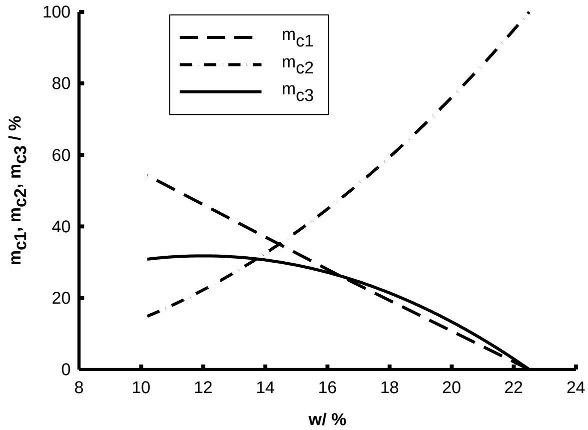

Figure 4 The percentages m_{c1}, m_{c2}, m_{c3} depending on the moisture of seeds -w for the genotype Aida at single impact which is parallel to the capsule's length and F_{in}=5.5E-4 N

The proportion of seeds released after smooth rotation of the capsules with the top down for the studied genotypes is presented in Table 2. At the middle moisture, the smallest percentage of m_{c1}=30.6% has the genotype Aida, and the largest - Valya with m_{c1}=71.0%, which is 2.32 times more. The difference has been due to the seed attached to the placenta and to the shape of the capsules. The Aida's capsules have narrowing directly beneath the top, which reduces the proportion of m_{c1}.

The results of t-test for the percentage m_{c1} give evidence for significant statistical differences of Aida from all other genotypes. For the Nevena genotype it is analogical. There are not significant statistical differences for the percentage of m_{c1} between genotypes Valya, Milena and 4090 and 4079 at a significance level of 0.05. These results have been obtained through testing 60 capsules of each genotype.

Table 2 The proportion of seeds released after smooth rotation of the capsules with the top down at the middle moisture

Genotypes	m_{c1} (%)		
	average	standard deviation	difference of Aida
Aida	30.6	2.9011	-
Nevena	55.4	2.8672	24.8
Valia	71.0	3.4216	40.4
Milena	45.0	2.2812	14.4
4090	50.8	2.5238	20.2
4079	67.3	2.4097	36.7

For the percentage of mc2 and mc3 have been got the following equations:

For Aida

m_{c2}=113.3991-13.6540 F_{in} , R^2=0.92, p=0.03;

m_{c3}=-44.1540+13.6856 F_{in} , R^2=0.93, p=0.02;

For Nevena:

m_{c2}=65.9970-7.6331 F_{in} , R^2=0.95, p=0.01;

m_{c3}=-19.0383+7.2239 F_{in} , R^2=0.88, p=0.049;

For Valia:

m_{c2}=11.4012-0.2844 F_{in} , R^2=0.87, p=0.053;

m_{c3}=14.5187+0.8766 F_{in} , R^2=0.86, p=0.054;

For Milena:

m_{c2}=70.7202-7.7260 F_{in} , R^2=0.88, p=0.055;

m_{c3}=-15.0587+7.5979 F_{in} , R^2=0.88, p=0.049;

For 4090:

m_{c2}=44.9586-5.0231 F_{in} , R^2=0.93, p=0.02;

m_{c3}=2.6637+5.3353 F_{in} , R^2=0.83, p=0.06;

For 4079:

m_{c2}=39.4577-4.8336 F_{in} , R^2=0.89, p=0.047;

m_{c3}=-11.3867+5.7347 F_{in} , R^2=0.94, p=0.01;

For all genotypes except Valya, the increasing of the inertial force F_{in} leads to proportional decreasing of the seeds that remain in the capsules after impact (Figure 5). The graph of Aida is most tilted which evidences that it is the most influenced by F_{in}. The moisture decreasing of the seeds and the capsules at maturation leads to increasing the effect of the inertial force F_{in} over m_{c2} due to a reduction the durability of the connection between the seeds and the placenta.

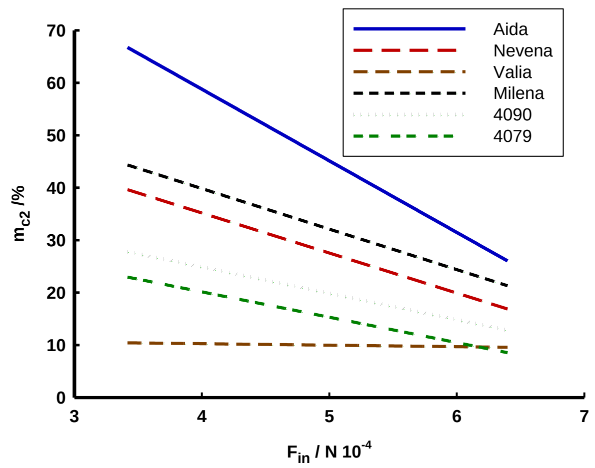

Figure 5 The percentage of seeds remaining in the capsules after the inertial impact depending on inertial force F_{in}

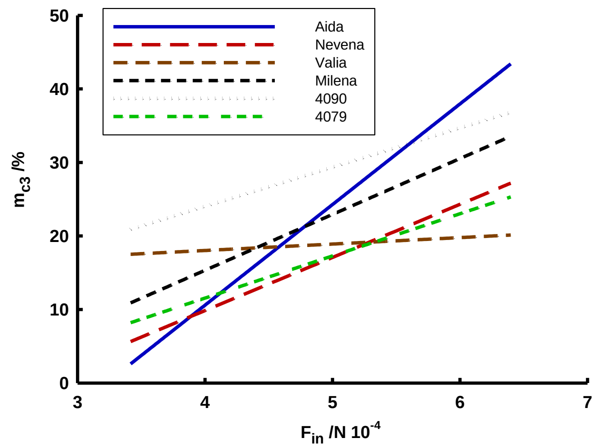

Figure 6 Percentage of seeds, having left the capsules caused by single inertial impact, which is parallel to the length of the capsules - m_{c3} depending on the inertial force F_{in}.

The increase of the inertial force F_{in} leads to a proportional increase in the percentage of m_{c3} (Figure 6). The graph of genotype Aida concludes the largest angle with the horizontal axis, which proves that it has reacted most strongly to the inertial force. When its value is 6.4 E-4 then the percentage of seeds, released by a single impact directed along the length of the capsules, has reached m_{c3}=40.8%.In fact, this impact can release from the capsules $m_{c1}+m_{c3}$= 77.4% of seeds at 15.1% moisture and $m_{c1}+m_{c3}$= 95.3% at 10.2% moisture. It is worth to state that risk of scattering seeds increases greatly at lower moisture. The genotype Valya has not reacted significantly to inertial force increase, which is explained by the peculiarities of its capsule.

The genotypes Aida and 4079 have the same parents, but their graphics differ significantly (Georgiev, 2014). The reason is the longitudinal splitting of the capsules at maturation and moisture reduction, thereby increasing the percentage of m_{c1} and reducing of m_{c2} and m_{c3}.

The effect of the direction of inertial impact on the percentage of released seeds m_{c3} is presented in Table 3. The percentage of inertial released seeds has decreased with 12.9% for the genotype Aida by the transverse impact in comparison with the parallel impact. For the genotype Milena such reduction has not been observed. The results of the t-test for m_{c2} and m_{c3} have been analogous to those for the m_{c1}.

Table 3 The percentage of seeds leaving the capsules caused of an inertial impact with F_{in}=5.49 E-4, depending on its direction toward the length of the capsule

genotypes	m_{c3} (%) transverse impact		parallel impact		difference
	average	st. deviation	average	st. deviation	
Aida	25.9	2.9011	13.0	2.1823	12.9
Milena	23.9	2.2812	23.9	1.9620	0

To explain the results let analyze the reasons for release of seeds from the capsule due to the inertial force in both directions of impact. In these cases run two processes:

- Seeds tearing from the placenta;

- Seeds leaving through the opening of the capsule.

The first process is depended by the angle of the positioning and securing of the seed towards the placenta. This angle is about 30° for the tested genotypes. Therefore, the inertial force has created tension and bending at the point of attachment of the placenta to the seed. On other hand, it is known that the force required for detachment of the seed by bending is much less than that by stretching (Ishpekov, 2012). Therefore, the transversal inertial force has detached more seeds than the longitudinal.

The second process flows more easily by the longitudinal directed inertial force, because the seeds go freely through the opening of the capsule. Under the effect of the transversal inertial force, the walls of the capsule reflect seed before their leaving.

The seeds release is also influenced by the shape of the capsules. It can be a parallelepiped or a truncated pyramid, which is oriented with large base to the top or to the handle of the capsule.

In the first case, the retention of the seeds in the capsule is slightly influenced by its shape. This is valid for genotype Valya, which has the largest percentage ofm_{c1} = 71.0%.The rest 29.0% of the seeds are pressed by the narrow spot and have remained at the bottom of the capsule. Its ringent tip helps to release the seeds by tilting or shaking.

The capsules of Milena, Nevena and 4090 have the shape of a truncated pyramid, which is oriented with large base to the top. Thus, they restrain seeds at the base of the capsule. These seeds can be released only after capsule destruction. The capsules of Aida and 4079 have the shape of a truncated pyramid, which is oriented with its large base to the stem. This shape of the capsules has influenced for reducing the percentages of m_{c1} and $m_{c2}$and for increasing of m_{c3}.

The percentage of the seeds that has left the capsules - m_{c3} is proportional to the number of inertial impacts for genotype Aida (Figure 7). The largest percentage of separated seeds m_{c3} = 19.9% has been caused by the first impact. Each subsequent impact released extra 9.2-11.4% of the total quantity of seed. It can be assumed that the required number of transverse impacts with an inertial force F_{in} = 5.49 E-4 N and an acceleration a_{in}= 133.8 m/s^2 to releasing of 95% of the seed must be over 10.

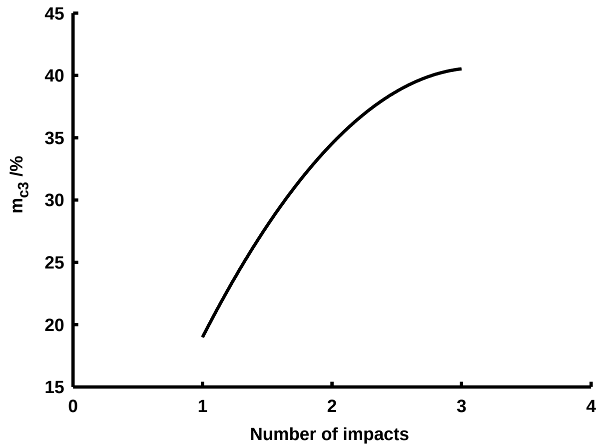

Figure 7 Graph for percentage of seeds that has left capsules - m_{c3} depending on the number of transverse impacts with an inertial force F_{in}=5.49 E-4 N for genotype Aida with a moisture of seeds 15.1%

The results have shown a real opportunity to harvest sesame seeds with humidity to 14÷16% by inertial impacts. They should give the plants accelerations about of a_{in}=8-14*g.

When threshing sesame plants with moisture 15.1% then the stems are very tough and the proportion of seed is around 5%. Aiming to release the seed, the stems and the capsules are deformed significantly, which requires relatively high energy. In these conditions, part of the seeds releases their fat, which lowers the efficiency of the threshing unit and the cleaner of the harvester. At inertial harvesting, deformation of the stems and capsules is not necessary. Only supplement of impacts with significant acceleration is required.

The inertial releasing of the seeds differs from threshing by the following features:

- The process is possible and reliable at humidity twice higher, which implies a reduction of scattered seeds;
- Reduction of mechanically damaged seeds;
- Helps separation of impurities from the seeds;
- Reduced energy consumption.

The obtained results can be used to develop technologies for one stage harvesting of sesame seeds with humidity up to 14÷16% by inertial effects, while the plants are on roots.

4 Conclusions

The seeds of tested sesame genotypes are released without breaking up of the capsules by inertial impact with a force over 3.5 E-4 *N*.

At seed moisture 14÷16%, the single inertial impact, which is parallel to the capsule length with a force 5.49 E-4 *N* and acceleration 133,8 m/s^2, has released from 52.4% to 83.8% of total seeds. The percentage of the released seeds has grown to 86% at lowering humidity of the seed to 10÷11%.

When the impact is applied transverse the capsule, the percentage of released seed are 0% for Valia and 19.9% for Aida. Each subsequent impact has released extra 9.2÷11.4% of total seeds in the capsules for Aida. Therefore, the required number of impacts for releasing 95% of the seeds has reached 10.

Best suited for inertial harvesting is the genotype Aida, because the release of its seeds depends strongly on the applied inertial force.

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